RESEARCH ARTICLE OPEN ACCESS

Implementation of closed loop control technique for improving the performances of PWM inverter-A review

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Abstract-
this review paper presents closed loop control techniques for controlling the inverter working under different load or KVA ratings. The control strategy of the inverter must guarantee its output waveforms to be sinusoidal with fundamental harmonic. For this purpose, close loop current control strategies such as H_∞ repetitive controller, dual closed-loop feedback control, Adaptive Voltage Control, SRFPI controller, Optimal Neural Controller, etc. have been used to meet the power quality requirements imposed by IEEE Interconnection Standards. Based on present scenario regarding energy crises, immediate action is the use of different renewable energy sources (RESs) . Out of RESs, solar is gaining more attention. It is very important to design and developed a system which should be efficient enough to utilize the extracted energy for different types of load and feeding of energy into utility grid. Since experimentation and comparison of such inverter models on hardware being relatively expensive, the latest computing tool like MATLAB are considered to be a better alternative to simulate the outcomes of such expensive systems. The proposed closed loop control technique for the inverter working under linear and nonlinear system will be implemented in MATLAB/SIMULINK working platform and results will be analyzed to check its benefits.
Keywords: Controller, harmonics, RES,ONC, *load voltage*

I. Introduction-

Integration of Renewable Energy Sources (RESs) in the Power Distribution System (PDS) to meet the demand of end users has prompted major efforts in the development of an efficient and low cost interface between the RESs and the grid [1]. The interface is called as Inverter which conditions the RESs output appropriately to meet the grid requirements as per the IEEE Interconnection Standards [2-4]. This inverter also offers the facilities such as "buck" or "boost" the available DC voltage, DC power into high quality AC, Maximum Power Point Tracking (MPPT) in PV and wind systems [5]. As the RESs can only follow the voltage of grid as required by Standards, power quality mainly depends on the inverter output current [6]. To meet those standards, a high performance current control of inverter plays a predominant role in feeding a grid with high quality power [7]. From the source basis, the grid connectable inverter can be categorized into single or three phase current-controlled (current source) and voltage-controlled (voltage source) types [8-9]. Both converts the DC power of RESs to AC power and inject into power feeder. Compared to single-phase inverters, three-phase inverters have distinctive advantages: the power flow is constant, which results in reduced capacitor value and fewer switches are used for three-phase DC-AC conversion compared to single-phase inverters [10]. To avoid introducing distortions to the power grid, the generated currents from these inverters are required to have low harmonics and high power factor [11]. Exceeding the harmonic injection limits may require the inverters to disconnect from the grid [12]. Typically, simple inductors L or LCL are used as a filter interfacing inverter and mains to attenuate the high-frequency current harmonics [13-14]. LCL filter provides advantages in costs and dynamics since smaller inductors can be used but had the demerit of resonance [15]. Hence, control systems involving LCL filters are inevitably more complicated. Among the typical current controllers, a proportional-integral (PI), hysteresis controller, predictive controller, repetitive controllers, iterative learning controller, integrators in multiple rotating frames, Proportional resonance (PR) regulator and resonant integrators have been used in order to mitigate the low-order current harmonics [16-19]. A Current Controlling inverter control is usually a double-loop structure: an outer voltage loop to regulate the DC-bus voltage and an inner current loop, which regulates the inverter output currents according to the reference signal provided by the voltage loop [20].

II. Controller-

in typical feedback system controller compares the feedback signals from the output with the desired output. The controlled output is the actual output and the desired out is the reference input. The difference between the feedback signal and the reference input is the actuating signal. The controller generates a proper control signal that finally control the system to reduces the error and hence to get the desired output. Controllers are classified based on their control action. The different types of basic control action are proportional feedback, Integral feedback, Derivative feedback and combination of these.

The PID controller involves three components proportional feedback, Integral feedback; Derivative feedback as shown in Fig. 1 By tuning the three components (gains), a suitable control action is generated that leads to desirable closed loop response of the output.

III. Concept of PID Design-

The proportional component determines the reaction to the current value of the output error. It serves as a "all pass" block. The integral component determines the reaction based on integral (sum) of recent errors. In a way, it accounts for the history of the error and serves as a "low pass " block. The derivative component determines the reaction based on the rate of change of the error. In a way, it accounts for the future value of the error and serves as a "high pass " block.

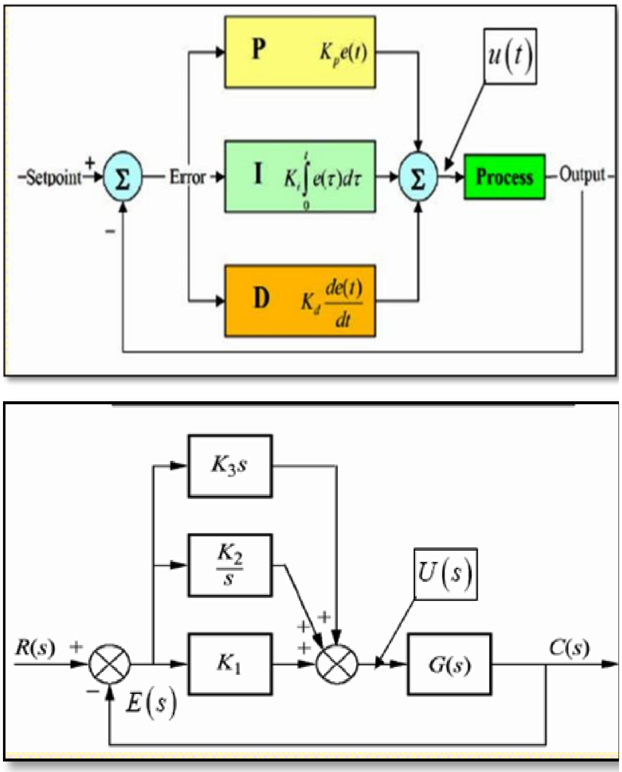

Fig. 1 Basic block of PID Controller
[N.S. Nise: Control System Engineering;4^{th} Ed.Wiley,2004]

***The final form of the PID algorithm is** :[21]*

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d(\tau) + K_d \frac{d}{dt} e(t)$$

$$\frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d s$$

The tuning parameters are:
Proportional gain,K_p
Integral gain, $K_i = K_p/T_i$
Derivative gain,$K_d = K_p T_d$.

Effect of proportional term:

$P_{out} = K_p e(t)$
P_{out} =Proportional term of output.
Kp=proportional gain (a tuning parameter)
The controller is given by equation 1,with Ti=∞ Td=0 there is always a steady state error in proportional controller. The error will decrease with increasing gain, but the tendency towards oscillation will also increase.

Effect of integral term:

$\boldsymbol{I_{out}=K_i \int e(\tau)dt}$
$\boldsymbol{I_{out}}$ = Integral term of output
$\boldsymbol{K_i}$ = Integral gain, a tuning parameter
The effect of addition of integral term, the strength of integral action increase with decreasing integral time Ti. The steady state error disappears when integral action is used and tendency of all oscillation also increase with decreasing Ti.

Effect of derivative term:

$D_{out} = K_d \frac{d}{dt} e(t)$

K_d= Derative gain(a tuning parameter)

In derivative action the parameter are chosen so that the closed loop system are oscillatory. Damping increase with increasing derivative time, but decrease again when derivative time becomes too large. The derivative action can be interpreted as providing prediction by linear extrapolation over the time Td. Using this interpretation it is easy to understand that derivative action does not help if the prediction time Td is too large.

Limitations of PID control

While PID controllers are applicable to many control problems, and often perform satisfactorily without any improvements or only coarse tuning, they can perform poorly in some applications, and do not in general provide optimal control. The fundamental difficulty with PID control is that it is a feedback system, with constant parameters, and no direct knowledge of the process, and thus overall performance is reactive and a compromise. PID controllers, when used alone, can give poor performance when the PID loop gains must be reduced so that the control system does not overshoot, oscillate about the control set point value. They also have difficulties in the presence of non-linearity. The most significant improvement is to incorporate feed-forward control with knowledge about the system, and using the PID only to control error. Another problem faced with PID controllers is that they are linear, and in particular symmetric. Thus, performance of PID controllers in non-linear systems is variable.

Related work for grid connected single or three phase bridge converter with closed loop control strategy:

Hornik *T et al.* [22] have proposed a current-control strategy for voltage-source inverters in micro-grids. The main objective of the proposed controller was to inject a clean sinusoidal current to the grid, even in the presence of nonlinear/unbalanced loads and/or grid-voltage distortions. The repetitive control technique was adopted because it can deal with a very large number of harmonics simultaneously. The proposed current controller consisted of an internal model and a stabilizing compensator, which was designed by using the H_∞ control theory. It turned out that the stabilizing compensator might be simply an inductor which led to a very low total harmonic distortion (THD) and improved tracking performance. The proposed controller performance was compared with the traditional proportional-resonant, proportional-integral, and predictive deadbeat controllers to demonstrate its superiority. The control strategies were evaluated in the grid-connected mode with experiments under different scenarios: steady-state and transient responses without local loads, and steady-state responses with unbalanced resistive and nonlinear local loads. The proposed controller significantly outperformed the other control schemes in terms of the THD level, with the price of slightly slower dynamic responses.

Zhilei Yao et al. [23] have presented a control of single-phase grid-interactive inverters with nonlinear loads. The waveform qualities of the grid current in grid-connected mode and the output voltage in stand-alone mode were poor under the nonlinear critical load with the conventional control. The impact of the nonlinear load on the grid current was analyzed and proposed control was illustrated in detail. By adding the load current into the filter inductor current loop, the influence of the nonlinear load on the grid current could be eliminated, and the waveform quality of the output voltage in stand-alone mode could be improved. The proposed control method was simple and easy to be achieved. The grid-connected inverter was stable at both modes. The filter inductor was chosen. Simulation and experimental results from a 1-kW dual-buck full-bridge grid-interactive inverter with a diode rectifier load verified the theoretical analysis.

Zheng Wang et al. [24] have proposed collaborative operation schemes of superconducting magnetic energy storage (SMES) for the current source inverter fed distributed power system (DPS) under the islanding mode. The key was to propose the closed-loop output voltage control for the current source inverter fed SMES to support the bus voltage at point of common coupling when the DPS was disconnected from the main grid. The droop control of voltage amplitude and frequency was designed to make different SMES units share the loads in DPS equally. To mitigate the effect of uncertain line impedance on power sharing, the virtual impedance control was added to construct a virtual output inductance for the SMES. The grid-connected operation was also proposed for the SMES to provide stable output power when the DPS is connected to the main grid. The computer simulation was carried out to verify the performance of the proposed operation schemes.

Shungang Xu et al. [25] have analyzed the output characteristics of a single-phase inverter with voltage and current dual closed-loop feedback control, and the equivalent circuit model of a parallel single-phase inverter system was also introduced. By taking both resistance and inductance components of the equivalent output impedance into consideration, a current decoupling control strategy of the parallel inverter system was then proposed. Furthermore, by constructing a three-phase balanced current according to the output current of the single-phase inverter, an active and reactive current decomposition method was presented to decompose the output current of the single-phase inverter into active and reactive currents according to the instantaneous reactive power theory. The block diagram of the active and reactive current decomposition method was given, and current decomposition simulation results were shown to verify the analysis results. The prototype was developed, and the control of two parallel-connected 2-kVA inverters was realized. The experimental results showed its feasibility and effectiveness.

Jin-Woo Jung et al. [26] have proposed a robust adaptive voltage control of three-phase voltage source inverter for a distributed generation system in a standalone operation. First, the state-space model of the load-side inverter, which considered the uncertainties of system parameters, was established. The proposed adaptive voltage control technique combined an adaption control term and a state feedback control term. The former compensated for system uncertainties, while the latter forced the error dynamics to converge to zero. In addition, the proposed algorithm was easy to implement, but it was very robust to system uncertainties and sudden load disturbances. A stability analysis was also carried out to show the robustness of the closed-loop control system. The proposed control strategy guaranteed excellent voltage regulation performance (i.e., fast transient response, zero steady-state error, and low THD) under various types of loads such as balanced load, unbalanced load, and nonlinear load. The simulation and experimental results were presented under the parameter uncertainties and were compared to the performances of the corresponding nonadaptive voltage controller to validate the effectiveness of the proposed control scheme.

Monfared M et al. [27] have designed a SRF multi-loop control strategy for single-phase inverter-based islanded distributed generation systems. The proposed controller used an SRF proportional-integral controller to regulate the instantaneous output voltage, a capacitor current shaping loop in the stationary reference frame to provide active damping and improve both transient and steady-state performances, a voltage decoupling feed forward to improve the system robustness, and a multi resonant harmonic compensator to prevent low-order load current harmonics to distort the inverter output voltage. Since the voltage loop works in the SRF, it was not straightforward to fine tune the control parameters and evaluate the stability of the whole closed-loop system. To overcome this problem, the stationary reference frame equivalent of the voltage loop was derived. Then, a step-by-step systematic design procedure based on a frequency response approach was presented. Finally, the theoretical achievements were supported by experimental results.

Motivation for the research work

From the review of the research work, inverter was working as interface between the grid and RESs and operated in standalone (island) and grid connection mode. The main purpose of this interface was to support the utility at the local load during both modes. Under unbalance loads, nonlinear loads, sudden load disturbances and system uncertainties; it should support the grid with unity power factor and low harmonic current injection (THD should be less than 5%). The key to make the inverter more robust to the mentioned conditions was its output current control strategy. The control strategy of the inverter must guarantee its output waveforms to be sinusoidal with fundamental harmonic. For this purpose, close loop current control strategies such as H_∞ repetitive controller, dual closed-loop feedback control, Adaptive Voltage Control, SRFPI controller, etc. have been used to meet the power quality requirements imposed by IEEE Interconnection Standards. The designing of H_∞ repetitive controller is quite complex due to its computations and other techniques also have complexities such as decomposition of output current using reactive power theory and working on SRF theory. These complexities have made difficulty in designing the closed loop control algorithm of inverter. In literature, some of the technical papers on grid connected inverters; they have not considered its output voltage THD and most of the algorithms are not tested under nonlinear loads and system uncertainties. So, the above mentioned problems have motivated to do this research work.

Proposed methodology

Considering the complexities in designing of closed loop control algorithm for inverter a hybrid closed loop control technique has been proposed for controlling the inverter working under linear and non-linear systems. This technique is proposed to generate a control signal which accomplishes the inverter output as per the load requirement whether it is linear or nonlinear. The input to the hybrid technique is the error between instantaneous actual and reference value of the load voltage. The reference value of load voltage is computed continuously online by taking into consideration of grid voltage, power factor angle and power angle. The performance of load dynamics due to the proposed control technique will be analyzed. The proposed hybrid closed loop control technique for the inverter working under linear and nonlinear system could be implemented in MATLAB/SIMULINK working platform and results could be analyzed to check its benefits.

IV. Conclusion

The proposed control technique which generates the control signals by considering load voltage error and change in error for improving the performance of PWM inverter. The comparison and performance analysis of signal phase and three phase PWM inverters is to be studied on the basis of different closed loop controllers, different sources (PV and Battery) different load or KVA ratings. The performance of inverter could also be studied by considering the parameters such as power factors, conversion efficiency, nature of output voltage and current, etc. The suitable control technique could be implemented for the experimental set up using a digital signal processor for improving the PWM signals.

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